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EVALUATION OF THE COHORT II MONTE CARLO SHIELDING CODE: GAMMA RAY TRANSPORT USING SOURCE DIRECTION BIASING

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An evaluation of the gamma ray transport portion of the COHORT II Monte Carlo shielding code is presented. This evaluation was accomplished by solving the point source, infinite medium, scattering problem and comparing COHORT II output spectra with the widely accepted moments method solution of the same problem. In addition, the COHORT II source angular biasing option was shown to be a valid technique for reduction of variance.

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SUMMARY

An evaluation of the gamma ray transport portion of the COHORT II Monte Carlo shielding code is presented. This evaluation was accomplished by solving the point source, infinite medium, scattering problem and comparing COHORT II output spectra with the widely accepted moments method solution of the same problem. In addition, the COHORT II source angular biasing option was shown to be a valid technique for reduction of variance.

INTRODUCTION

Nuclear reactors and radioisotopes are being considered as potential energy sources for some space power systems. For both manned and unmanned missions, the design of adequate radiation shielding and the reduction of component radiation heating is essential. Manned mission studies indicate the weight of the shield material to be a large fraction of total system weight. Attempts to reduce shield weight are directed toward optimization of shield geometry and increased confidence in radiation attenuation calculations. Optimized designs will usually assume a variety of unusual geometric configurations which can be calculated, without recourse to idealizing assumptions, only by the use of Monte Carlo methods.

The speed and accuracy of any Monte Carlo technique are dependent on the incorporation of variance reduction schemes to reduce statistical uncertainties in the results to reasonable levels. Without these schemes, Monte Carlo scattering problems involving deep penetrations or irregular geometries would require considerable machine time to produce statistically acceptable results. For this reason, variance reduction techniques such as Russian roulette, statistical estimation, biasing of source energy and direction, and exponential transformation should be included in any Monte Carlo procedure.

This report evaluates the gamma ray transport portion of the COHORT II program (ref. 1). This program is a completely revised version of the original COHORT code and includes options for all of the variance reduction techniques mentioned previously. Specifically, this report presents the solutions of the point source, infinite medium, gamma ray scattering problem by both the unbiased and biased options of COHORT II and compares the output spectra with the widely accepted moments results (ref. 2). These comparisons serve as an accepted test of the particular variance reduction technique used and of the revised methods and routines incorporated in the code.

The solutions presented in this report are based upon tracking 10 000 histories from a point source of 3-MeV gamma rays located at the center of a homogeneous aluminum sphere. The moments method solution of this problem is found in reference 2. Two types of detectors were located at penetrations up to 7 mean free paths from the source: point detectors (to measure flux at a point) and spherical shell detectors (to measure flux in a volume). Also, point detectors were used to test the validity of the source angular biasing option. Unbiased results were also analyzed and are presented for comparison with source direction biased results.

DESCRIPTION OF THE PROBLEM

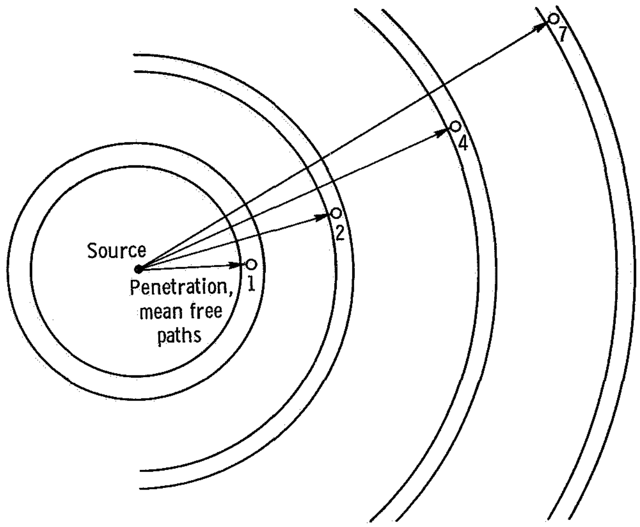
The following point source infinite medium problem was established to serve as the basis for comparison of COHORT II and moment methods solutions.

Source-Detector Geometry

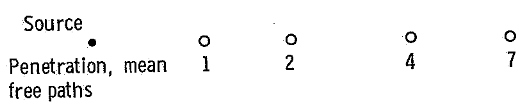
The geometry used for the comparison consisted of an isotropic 3-MeV gamma point source located at the center of a homogeneous aluminum sphere (fig. 1). Detectors were located at 1, 2, 4, and 7 mean free paths, corresponding to 10.5, 21, 42, and 72.5 centimeters, from the source point. Both spherical shell and point detectors were utilized to provide flux-in-a-volume and flux-at-a-point results, respectively. For this problem point detectors were positioned along a 0° polar angle with respect to the source.

Source Angular Distributions

Two types of source angular distributions were utilized. One was an unbiased isotropic distribution for calculation of penetrations for both the flux-at-a-point and flux-in-a-volume detectors. The second distribution was biased in the direction of the de-



(a) Volume (spherical shell) detectors.



(b) Point detectors.

Figure 1. - Source-detector geometry for comparison of solutions.

tector points and was utilized for flux-at-a-point calculations only. Both distributions are shown graphically in figure 2, which plots particle weight and polar angle.

The unbiased distribution carries a particle weight of 1 over the entire range of polar angles. This represents the true physical distribution of a point isotropic source. However, for purposes of a finite history point detector calculation, the unbiased distribution is wasteful of particle histories because it does not emphasize production of particles in the direction of the detector point. The biased distribution is not an optimum choice but was based on the arbitrary assignment of particles into the angular intervals shown in table I.

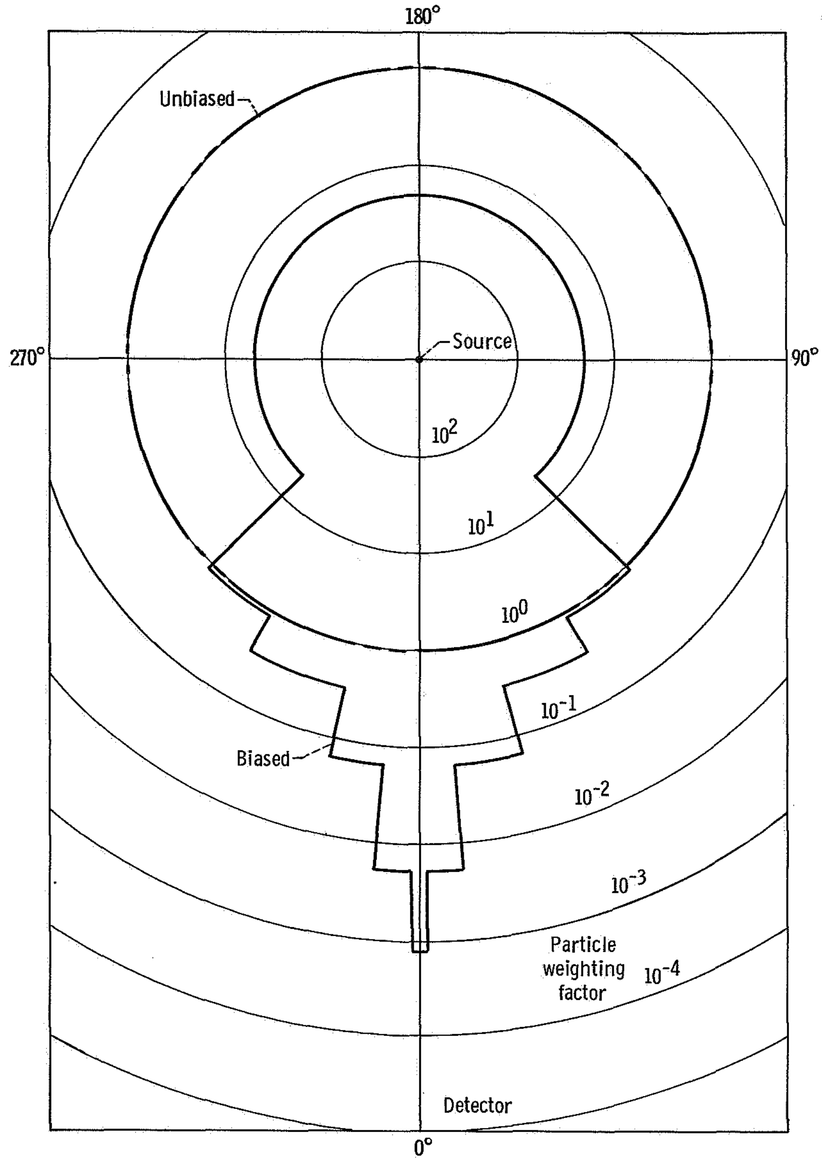


Figure 2. - Angular distributions and particle weighting factors for the point source (detector located at 0° polar angle).

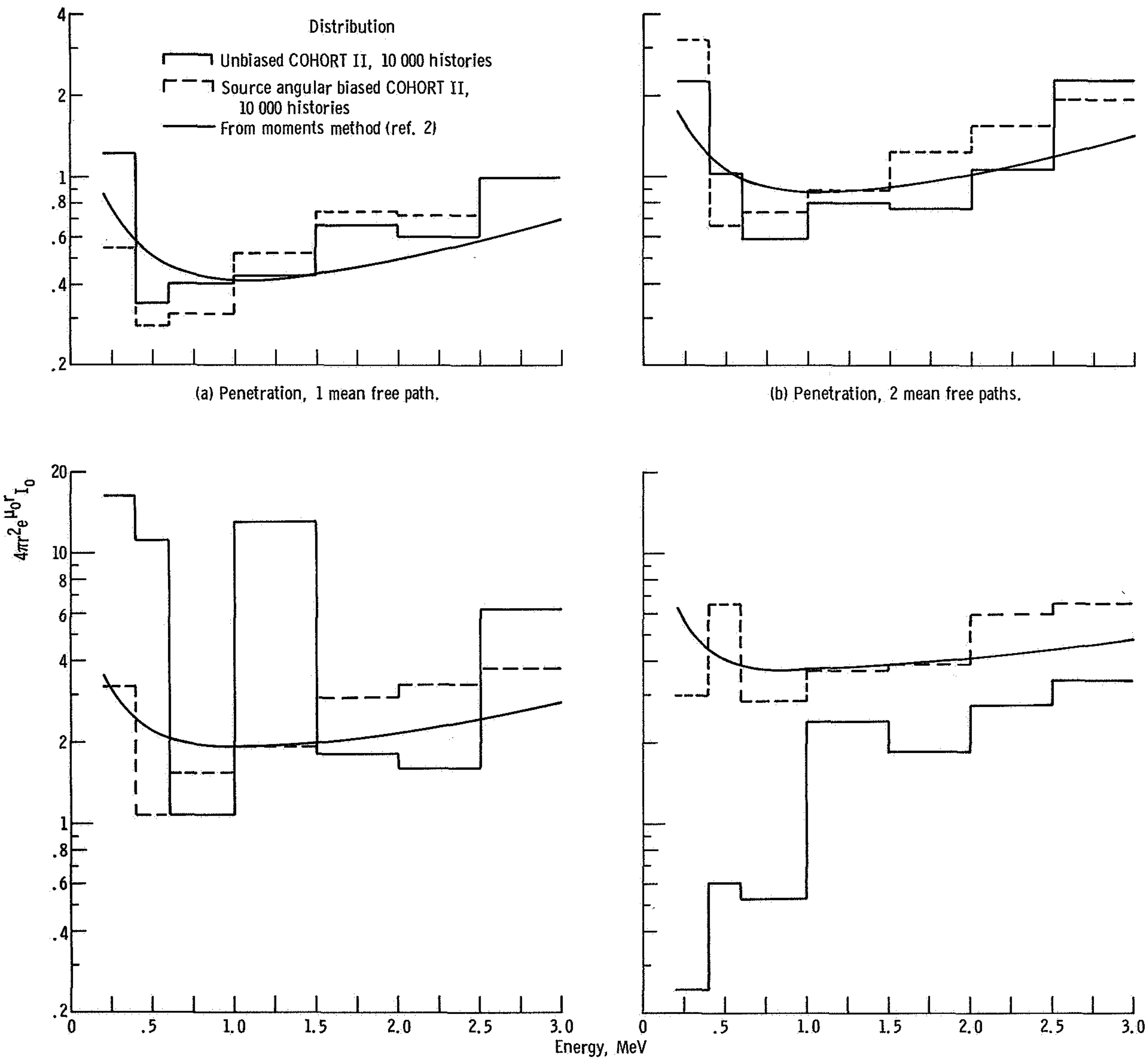
TABLE I. - ANGULAR SOURCE BIASING OPTION

Angular interval, deg	Fraction of source particles escaping	Particle weight
0 to 1	0.10	7.5×10^{-4}
1 to 5	.35	5.2×10^{-3}
5 to 15	.25	6.05×10^{-2}
15 to 30	.15	3.3×10^{-1}
30 to 45	.10	7.95×10^{-1}
45 to 180	.05	1.7×10^{1}

RESULTS AND DISCUSSION

Flux-at-a-Point Detector

Differential energy spectra are shown in figure 3 for 3-MeV photons in aluminum. Plots of $4\pi r^2 e^{\mu_0 r} I_0$ as a function of energy are presented for penetration distances of 1, 2, 4, and 7 mean free paths in order to compare biased and unbiased COHORT II results with the corresponding moments method calculations (r is distance from source to detector, μ_0 is the absorption coefficient at the source energy, and I_0 is the energy flux). In figures 3(a) and (b) both the baised and unbiased



(a) Penetration, 1 mean free path.

(b) Penetration, 2 mean free paths.

(c) Penetration, 4 mean free paths.

(d) Penetration, 7 mean free paths.

Figure 3. - Differential energy spectrum comparison of COHORT II flux-at-a-point data with moments method results for 3-MeV photons in aluminum.

COHORT II results, representing 10 000 histories each, show agreement within a factor of 2 of the moments method values for penetrations of 1 and 2 mean free paths. However, figures 3(c) and (d) ($\mu_0 r$ = 4 and 7) indicate that a considerable reduction in the fluctuations of the unbiased spectrum has been obtained by the use of source angular biasing. Note that these biased sampling results retain agreement within a factor of 2 of the moments method data.

Flux-in-a-Volume Detectors

Figure 4 presents the differential energy spectra for 3-MeV photons in aluminum at 1, 2, 4, and 7 mean free paths. The COHORT II unbiased results show very good agreement with the moments method calculations at all penetrations.

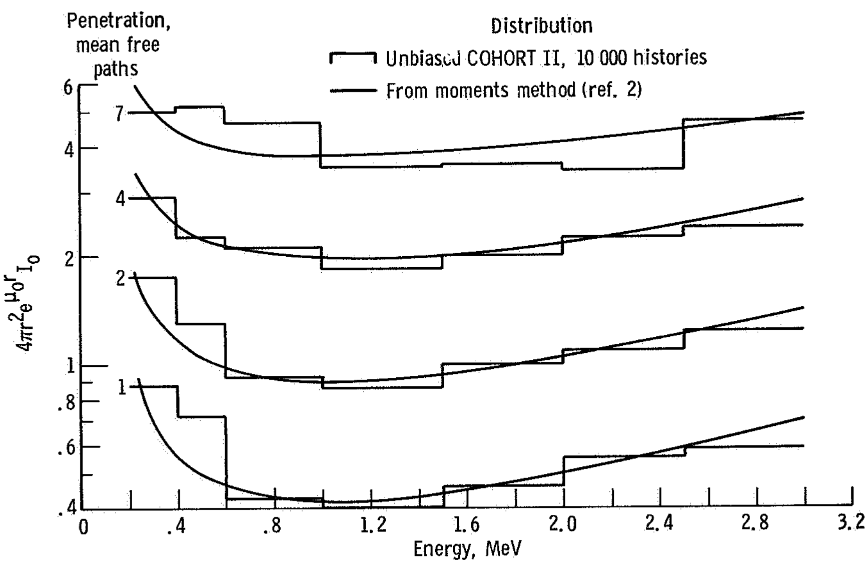


Figure 4. - Comparison of COHORT II flux-in-a-volume differential energy spectra with moments method results for 3-MeV photons in aluminum.

SUMMARY OF RESULTS

COHORT II Monte Carlo calculations were performed to obtain differential gamma ray spectra for the point source, infinite medium problem. The significance of the results may be described as follows:

1. The COHORT II results were shown to be within a factor of 2 of the moments method calculations of scattered gamma ray spectra in infinite media for both flux-at-a-point and flux-in-a-volume detectors for penetrations up to 7 mean free paths.

2. The source angular biasing option provided a considerable improvement over biased results in the variation of point detector differential energy spectra at the deeper penetrations investigated while retaining good agreement with moments method results.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 10, 1969,
120-27.

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